LstSim-Extended: Towards Monitoring Interaction and beyond in Web-Based Control Room Simulations ⋆

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Abstract. Control room operators rely on a range of technologies to communicate crucial information and dependably coordinate a disparate collection of tasks and procedures. Tools that are capable to design, to implement, and to evaluate interactive systems that can assist the tasks of control room operators in these environments therefore play an important role. This paper offers a framework that facilitates the early research steps into evaluating work flows, interfaces, and wearable sensors in the context of an emergency dispatch center. It entails a primarily web-based, quick-to-deploy, and scalable method that specifically targets preliminary studies in which large-scale and situated deployments are not feasible. By using open-source and affordable wrist-worn sensors, it furthermore enables investigating any relationships between interaction design in control rooms and operators' physiological data. Our evaluation on a preliminary study with 5 participants shows that basic scenarios are able to induce differences which can be measured by reaction times in the interactions as well as in the data from the wrist-worn sensor.

Keywords: Usable Safety and Security · Control Rooms · Web-based Simulations · Interfaces and Cognitive Load · Emergency Dispatch

1 Introduction

Control rooms are among the more critical human-computer interaction systems, as they play a crucial role in safeguarding the security and well-being of humans in a range of situations. Whether an emergency requires an ambulance to be dispatched, crucial traffic flows need to be managed, or to guarantee an uninterrupted supply of utilities such as power, gas or water, control rooms represent critical infrastructures and their operators bear substantial responsibilities.
While control rooms have changed considerably with respect to available information and communication technologies, human-machine task allocation and

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levels of automation within the last decades, user interfaces and interaction design in this area are still characterized by the windows, icons, menus, pointers (WIMP) paradigm, using established software available at stationary devices with displays of various sizes.

We propose in this paper an evaluation framework that aims at researching human-computer interaction aspects for emergency dispatch situations in a simplified but scalable manner. The contributions are threefold:

1. We extend a community-driven and web-based emergency dispatch simulator with a browser plugin and a web-based Bluetooth LE connection to a smartwatch. This allows us to monitor both user interactions and user vital signs during simulations.
2. We demonstrate that the browser plugin reflects the users' workflows and response times during the emergency simulations.
3. Users' realtime feedback can be measured by the user's smartwatch simultaneously. An evaluation on this data illustrates that certain features reflect significant changes between low-stress and high-stress scenarios.

The remainder of this paper is structured as follows: After section 2 is dedicated to related research in this area, we introduce the workings of LstSim in section 3. Our framework is then presented in section 4, detailing how we intend to monitor user interactions and user's smartwatch data during emergency dispatch simulations. Section 5 describes our first evaluations and experiences with deploying our framework. The results are then reported on and discussed in section 6, before we conclude our paper in section 7.

2 Related Work

Control rooms have been defined as "location[s] designed for an entity to be in control of a process" by [7]. Ethnographically-inspired workplace studies and contexts of use analyses (e.g. [5]; Wozniak et al., 2017) have provided insights into the complex socio-technical nature of control rooms and the challenges that their operators face. Apart from maintenance, two basic operating modes can be distinguished as identified by (Herczeg, 2014): First, *routine operations* are characterized by control room operators handling well-known and predefined tasks based on standard operating procedures and experience. Routine operations should not be confused with undemanding work, as they are mentally and physically challenging due to sedentary occupation, shift duty, lowered vigilance, alarm fatigue, and overall information overload[3]. Second, *emergency operations* to respond to incidents and accidents are characterized by control room operators trying to limit damages and bring the system state under time-critical circumstances back to a normal operation. Emergency operating procedures and contingency procedures might in this case be available to a certain degree.

Control room modernization has led to predominantly virtual interaction and control elements that are operated via desktop computers. The interface to such digital systems within control rooms is thus dominated by traditional desktop interaction following the windows, icons, menus, pointers (WIMP) paradigm. Studies have meanwhile confirmed that although such interactions tend to be faster to execute, control actions could be recalled significantly better using tangible interface elements [9].

Previous research has explored user-centered design processes to analyze how processes of management in critical environments such as control rooms can be optimized. Through interviews and site visits, prototypes using novel interaction techniques such as multi-touch, tangible and pen-based interactions were devised as demonstrators, to then gather feedback from operators [10]. Research exploring the potential of employing multi-modal interactive displays to support work and collaboration in control rooms indicates that it supports the feeling of control and safety during interactions, enables efficient access to information from a distance, and offers flexibility of use anywhere in the room [6].

Simulations to evaluate human-system interactions are a well-established method, with several studies investigating specific scenarios such as power plants [1] or police control rooms [4]). Simulations provide the opportunity to study control room procedures in a controlled environment. It is possible to play through certain scenarios and train defined situations. In contrast to observation in everyday use, the observer has more parameters available to control what happens. On the one hand, it enables safe observation without interfering with daily business as well as the generation and observation of rare events.

System that are aware of a user's experienced cognitive load may help improve performance in complex, time-critical situations such as control rooms. Since measuring a user's cognitive load in a robust fashion and in real-time is not a trivial task, research has explored using different, non-intrusive features such as linguistic features [8].

This paper proposes to complement the above to provide a method to elicit realistic control room scenarios and being able to measure the users' interactions and vital signs through wrist-worn devices, simultaneously. Our framework is easy to roll out, as it can be started from any study participants' browser and assumes only the presence of a low-cost smartwatch. This thus allows more in-depth research into interfaces and the effects of operators' vital signs at an early stage, without requiring potentially intrusive, on-site visits.

3 LstSim

The control room simulator LstSim, which is a shortened form from the German word for control room simulator ("Leitstellensimulator"), offers the opportunity to slip into the role of a dispatcher at a rescue control center through a browser-based game. The game's interface is a simplified replica of processes and software used in control rooms for the scheduling of emergency operations and patient transports. For an example screenshot of LstSim, see Fig. 1. The window is divided into five areas, which will be presented below.

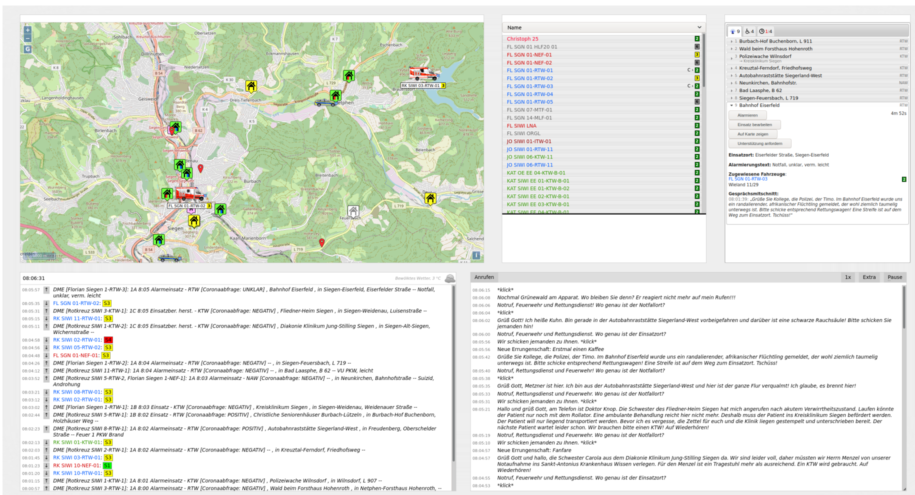

Fig. 1: LstSim is a control room simulator that can be played without registration online on `https://lstsim.de/`. Its interface incorporates elements from an emergency dispatch center into a single browser window, such as displays and controls through an overview map (top-left), lists of available units (top-centre) and current emergency phone calls (bottom-right).

The map is one of the main elements. It is shown in the upper left of the window. It is used for geographical orientation and overview of the current area of operation. It shows not only the entire road network, important places such as landmarks, or city districts, but also the vehicles that are currently in operation and the corresponding locations. In addition, the available rescue stations and hospitals are displayed on the map. In the Fig. 1 a rescue station is visible (green symbol with house). For the different rescue stations there are seven different symbols, which represent different types and different staffing. This increases the complexity, but also ensures a consistent representation. For example, there are symbols to indicate whether a rescue station is staffed with emergency ambulances, or with ambulances, or with patient transport vehicles, or with no vehicle at all. The map thus primarily provides a geographical overview of the entire deployment.

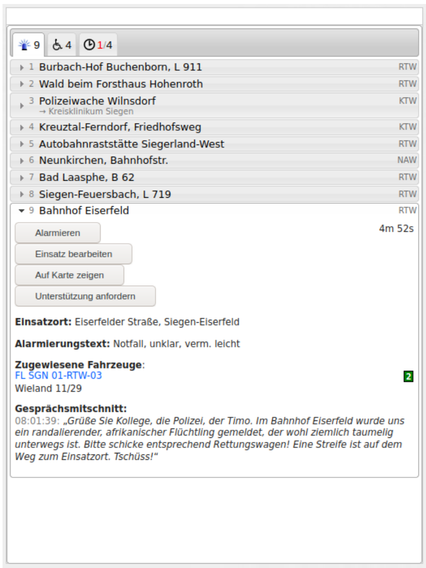

Fig. 2: LstSim Mission Module

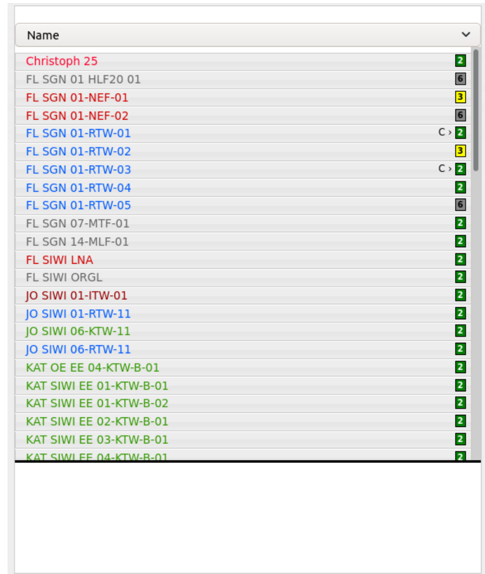

Fig. 3: LstSim FMS Module

In the Operations Overview module (see Fig 2), shown in the upper right corner, current and upcoming operations are listed. The list contains important information about each operation, such as location, assigned vehicles or alert text. There are three different categories of operations. First of all, there are missions with a special urgency. Furthermore, missions with a low priority are also displayed. These include ambulance transports and emergencies that are less urgent. Finally, there is also an overview of planned patient transports that will only be carried out in the future. A deployment can be edited, or displayed on the map. By editing a deployment, additional vehicles can be assigned, or the deployment can be terminated.

The radio reporting system ("Funkmeldesystem" / FMS) tableau, shown in the upper center to the right (see Fig. 3), of the control center simulator is used for the vehicle overview. At a glance you can see which vehicles are available for an operation and which vehicles are currently in operation. There are also further options in the FMS tableau. For example, it is possible to request the status of an emergency vehicle or to alert a vehicle. Similar to the map, the user also needs explicit knowledge for this window, such as knowledge of the individual FMS statuses, or which vehicles or vehicle types are behind the abbreviations. However, this provides the user with as real a simulation as possible.

The radio calls are essential to communicate with the currently deployed emergency forces, while the communication with requesting persons (citizens, care services, etc.) is done via telephone calls. Both channels are displayed in separate windows in the simulator. The radio calls in the lower left and the telephone calls in the lower right. The radio conversations contain only short information about status changes or status requests. The short messages keep the communication channel clear and status changes can be viewed quickly. The phone calls, on the other hand, contain the simulated emergency of the caller. As a result, the calls differ in length and speech style to reflect reality as closely as possible. Basically, the individual windows for radio and telephone calls differ only marginally in structure.

The main task of a dispatch center is to receive emergency calls, and to respond to the emergency calls by dispatching appropriate emergency personnel. The operational sequence is as follows: A new emergency arrives at the control center through a simulated call, which can be accepted. If the call is answered, the text of the caller appears in the phone call window. Based on the information contained in the call, a new operation must then be created. This requires the specification of an operation keyword and a transport type. These attributes can be selected from existing lists. Finally, at least one vehicle must be assigned to the operation. When these entries have been made, the operation can be created and the vehicles can be alerted at the same time. Once the operation has been created and the vehicles have been alerted, they are displayed on the map with their current location. During an ongoing operation, it can be edited at any time. When the operation is finished, the FMS status of the emergency forces changes automatically, so that they are ready for action again.

Also for the creation of an operation - especially for the specification of the operation keyword - the user needs a certain amount of expert knowledge in order to draw the right conclusions from the information of the telephone call.

Although the active development of LstSim has ceased in 2017 and no new updates are supplied, the scenarios which are available are quite realistic and retain a large and active user base. LstSim therefore remains an attractive browser-based (and thus low-fidelity) simulation environment for control rooms.

4 Our Framework

This paper proposes to build upon the rich community contributions that were implemented in the LstSim simulator, by adding (1) a browser plugin that captures all user interactions within it, as well as adding (2) a web-based Bluetooth connection to a low-cost, open-source smartwatch to get physiological data from the user during the simulations.

4.1 Browser Telemetry Plugin

The user's interaction with LstSim is recorded by a browser plugin. This hooks into the games engine and records various parameters of the game that allow a subsequent evaluation of the player's success. One parameter is the length of time until the player reacts to an incoming phone call as well as the time needed to process this call. The content of the phone call is also stored. This makes it possible to subsequently find the emergency in the database of all possible emergencies and to compare the user's solution with the correct solution. Furthermore, the rescue equipment selected by the user for the mission is stored. Another parameter stored is the time needed by the user to respond to incoming requests in the window for communication with the deployed rescue resources. Finally, the number of open missions divided into high priority missions, low priority missions and planned ambulance transports is stored. This gives an overview of how many simultaneous operations the user has to process.

The data is sent by the browser plugin to a back-end server and stored in a database for subsequent processing.

4.2 Browser-controlled Wristwatch

Fig. 4: The open-source Bangle.js smartwatch acquires a user's physiological data while an LstSim simulation is in progress.

The Bangle.js smartwatch was used to record the physiological data. In addition to acceleration sensors, this also provides a photoplethysmograpghy (PPG) sensor. The data from this sensor was primarily used for this work. The built-in sensor is a BD 1668 optical analog pulse sensor. It measures the reflection of the emitted light signal and thus determines the pulse rate. The Bangle.js allows to read this sensor directly, so that a PPG raw signal is available. The sensor is queried at a rate of 100 Hz. The smartwatch always aggregates 10 measurements to a data packet which is transmitted to the user's computer every 100ms. Here, the data packet is received via a browser-based Bluetooth Low Energy (WebBLE) interface and the measured values are displayed. The browser-based interface can be seen in Figure 5. After a completed experiment, the data can be downloaded as a CSV file for later analysis.

5 Evaluation

We recruited 5 participants (3 female, 2 male). The mean age was 27.6 years (SD = 3.07, min = 22 years, max = 31 years). 1 participant was left-handed. These participants were briefed by the author. All participants hat no prior knowledge of LstSim and no prior in depth knowledge about rescue operations and emergency responses.

Two scenarios were followed for a feasibility evaluation of our framework. The

Fig. 5: A web based framework is used to control the BangleJS wristwatch and to capture physiological data from the test participants while they go through the emergency dispatch center scenarios. The above plot shows photoplethysmography (PPG) data with the user's heartbeats visible as peaks.

study participants played each scenario for 10 minutes at a time on a provided laptop with a single screen. The first run was performed with the standard (relatively low) probabilities for the occurrence of an emergency. In the second run, the probabilities were increased by a factor of 40 instead. This provides an average of 0.8 calls per minute in the first run and 3.8 calls per minute in the second run. The increase in average emergency calls should provide a measurably higher cognitive load.

Name	Function	Hypothesis
Mean RR	Mean of RR	↓
IBI	interbeat interval	
SDRR	standard deviation of RR intervals	↓
SDSD	standard deviation of successive differences	
RMSSD	root mean square of successive differences	↓
pNN20	proportion of successive differences above 20ms	
pNN50	proportion of successive differences above 50ms	↓
MAD	median absolute deviation of RR intervals	
Breathingrate	the breathing rate of the subject	
LF	low-frequency, frequency spectrum between 0.05-0.15Hz	↑
HF	high-frequency, frequency spectrum between 0.15-0.5Hz	↓
HF/LF	the ratio high frequency / low frequency	↑

Table 1: Metrics used for evaluation and corresponding hypothesis about the reaction to congitive load

During the game, the PPG signal is recorded via Bangle.js wristwatch. For evaluation, the events in the game are used to determine metrics such as the call lead time, which indicates how long a call has to wait to be processed by the control room operator. On the other hand, vital signs metrics are calculated via the PPG signal: Table 1 shows these calculated metrics. For seven of these metrics we can hypothesize how they will react to the stress scenario [2]. This is also marked in the table. A downward pointing arrow means that this metric should decrease under stress, an upward pointing arrow means that this metric should increase under stress. To calculate the metrics, the PPG signal is first filtered. A bandpass filter with the frequency spectrum [0.75, 3.5] Hz is used. Then each metric is calculated on a window of 30 seconds length with an overlap of 0.25. Results for the PPG metrics are reported in Table 2.

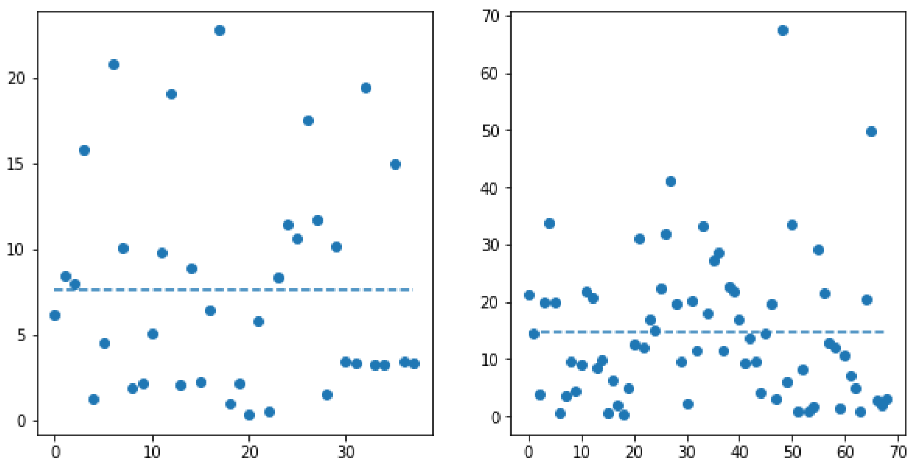

Fig. 6: Call lead time in seconds for low stress (left) and high stress scenario (right). The dotted line represents the mean value.

The call lead time increases from 6.81 secondes for the low stress scenario to 13.38 secondes for the high stress scenario as reported in Fig 6. This indicates that the volume of calls make it more difficult for the operator to adequately categorise and dispatch each call as well as that the time needed to handle a call leads to a pileup of follow up calls.

6 Discussion

The results of the preliminary study, even though they originated from a small amount of participants, contain several points of interest. It can be seen that the increase in call volume leads to a significantly higher workload for the participants. This is evident in the increased time to start processing a call. For the PPG metrics, only a few show up with a significant effect size. Only breathing rate and pnn20 show more significant effects. Here, statistically significant differences (p¡0.05) between the two groups are also found.

For the features RMSSD, SDRR, SDSD and HF, smaller effects can be observed but no statistically significant differences between the two groups can be found. For all other metrics no effect can be detected. The development of the

Name	Development	Cohen's d	p-Value
Mean RR	↑	0.2481	0.3364
IBI	↓	0.2917	0.2592
SDRR	↑	0.4720	0.0703
SDSD	↑	0.4536	0.0816
RMSSD	↑	0.5075	0.0521
pNN20	↑	0.6516	**0.0135**
pNN50	↑	0.4208	0.1056
MAD	↑	0.1419	0.5815
Breathingrate	↓	0.7044	**0.0078**
LF	↑	0.3663	0.1578
HF	↑	0.4889	0.0611
HF/LF	↑	0.0368	0.8859

Table 2: Results of the PPG metrics

observed metrics differs clearly from the hypothesis. Only for LF and HF/LF do the metrics follow the hypothesis. However, since no statistically significant difference between the metrics can be found here, no statement can be made as to whether this correlation is significant.

The difference between the observed metrics and the hypothesis can be explained by the small size of the study. A larger follow-up study should be conducted to further investigate the effects.

Limitations

The preliminary study described in this paper, with its small number and heterogeneity of study participants, makes it hard to establish statements about the size and impact of the observed effects on cognitive load. Likewise, a statistically valid statement about the direction of the observed effects in the selected metrics is not possible. Nevertheless, we argue that these results are encouraging and that the ease of which these results were obtained do show the promise of the presented methodology. We therefore are currently planning a larger study with expert users to delve deeper into studying how reliable we can characterize cognitive load in these settings.

Application Scenarios

There are several potential use cases in which our proposed framework can be deployed. The existing control room software is today rather challenging to use. An interesting study focus would therefore be to explore whether a detected potentially higher cognitive load can be attributed (1) to the user interface itself, (2) to the time pressure; or (3) whether this relates to the experience of the operator or the concrete situation in dispatching ambulances for critical or non critical emergencies. All of this research questions can be explored from within our framework before an actual in-situ study needs to be developed and performed.

7 Conclusions

In this paper, we have presented a web-based framework for the monitoring of interactions between control room systems and their operators. Building up from a popular and web-based simulator for dispatchers at a rescue control centre, we have added a telemetry browser plugin and a WebBLE-based wearable framework that monitors physiological data, such as the heart rate, from the operator's wrist.

A preliminary study with five participants has shown that this system is able to capture data from interactions and smartwatch simultaneously. The evaluation on a basic scenario shows that different phases show notable differences in reaction times. Features from the wearable photoplethysmography (PPG) sensor has furthermore illustrated that certain features display significant differences between low-stress and high-stress situations, across participants.

We currently plan a larger follow-up study, which is necessary to determine the significance of the observed effects, but the deployments – held during the COVID-19 pandemic – already show the ease and scalability of this approach.

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